



VBS - The Optical Rendezvous and Docking Sensor for PRISMA

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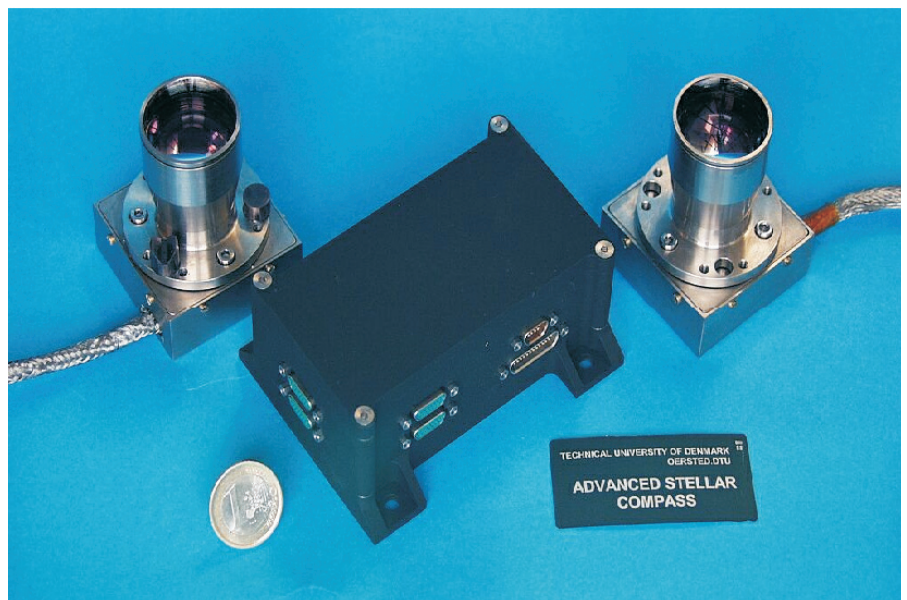
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VBS - The Optical Rendezvous and Docking Sensor for PRISMA.

One of the three rendezvous and docking sensor systems that provides the navigation information for PRISMA is the Visual Based System VBS. As the name indicates, the system is based on optical information, gathered by a set of cameras. The VBS is designed, developed and built by the National Space Institute, an institute at the Technical University of Denmark. The VBS has been based on the highly successful microASC platform, a fully autonomous high accuracy star tracker platform that is used worldwide as a high performance attitude recovery instrument onboard satellites. The standard microASC, as shown on figure 1, can drive from 1 to 4 CHUs, so as to provide continuous attitude information for even the most demanding space mission. The microASC platform, and its attitude performance, is fully space qualified, and it is at present delivered to more than 20 satellites worldwide.

The purpose of the VBS is to autonomously provide accurate relative pose and position information about the Target satellite, to be used for the navigation of the formation flying operations of the PRISMA satellite. In order to achieve the largest possible range of operations, the VBS is equipped with two different cameras that will cover different distance ranges; the VBS far



The microASC, here shown with 2 camera units.

camera covering from 10.000km down to 100m and the VBS short camera covering ranges from 500m down to a few centimeters. Because PRISMA is a low earth orbiting mission, the actual maximum acquisition range is somewhat smaller, because the Target satellite will dip under the horizon at distances larger than some 1800km.

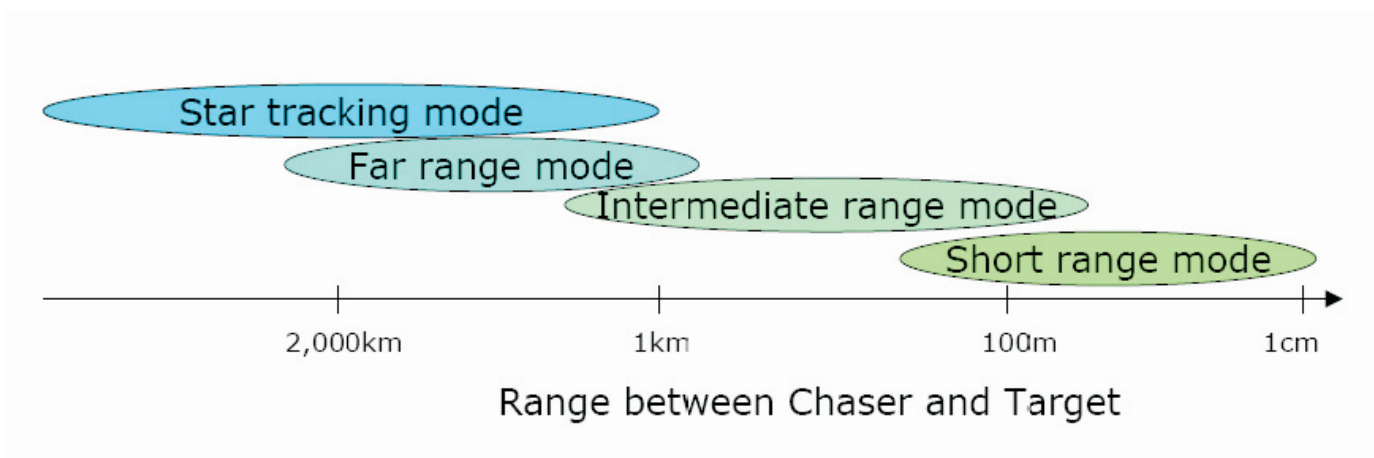
Since the VBS navigation information is used directly by the AOCS system of the Chaser satellite, the VBS system has been optimized towards robust and rapid operations. This choice has led to a system that prioritizes delivery of reliable and accurate information only at any given range, rather than trying to deliver a full position and pose solution, which in many cases will lead to excessive processing times.

The VBS system is required to operate fully autonomous, from first acquisition to close encounter. To achieve this in combination with the demand for high accuracy and fastest possible delivery of the solution to the AOCS system, the processing has been split to cover four different cases, and has thus resulted in four different modes of operations; Far range, intermediate range, short

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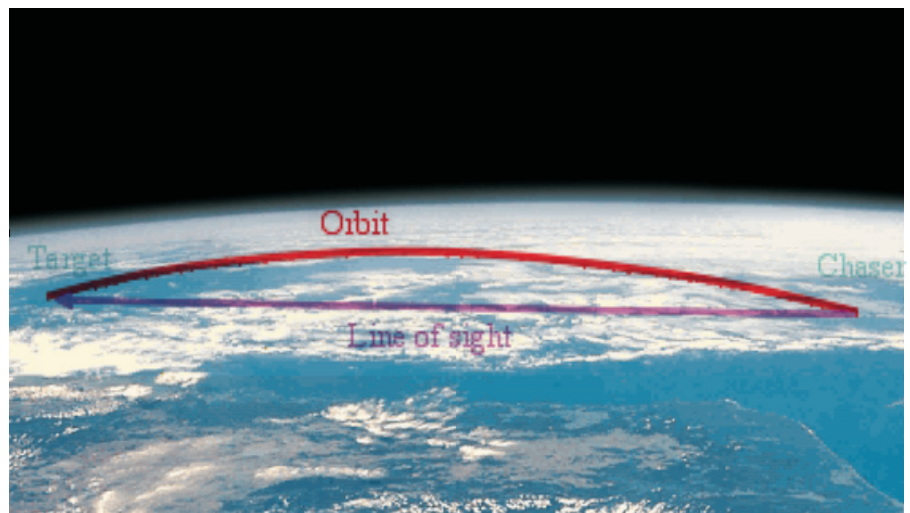


- **Attitude Mode.** The VBS DPU uses solely the standard CHU for attitude solutions.
- **Far range VBS mode.** The VBS DPU uses the standard CHU for searching and tracking target candidates, in ranges from 10,000 km down to 1 km.
- **Intermediate range VBS mode.** The VBS DPU uses the standard CHU to obtain the target direction and distance. Range: 5 km down to 200 m.
- **Short range VBS mode non-cooperative.** The VBS DPU uses the standard CHU to obtain the target direction, distance and pose. Range: 200 down to 20 m.
- **Short range VBS mode cooperative.** The VBS DPU uses the NIR CHU to obtain the target direction, distance and pose. Range: 100 down to 0.1 m.

range cooperative and short range non-cooperative. The latter two modes, is implemented to enable the testing of formation flying performance, both when the target satellite is trying to help the navigation and when it is not. The mode switching diagram is shown in figure 2.

The standard microASC platform has a huge processing power surplus, and because it has been designed as a image analysis engine, the only hardware modifications necessary to realize the VBS system has been a change in the optical pass band of the VBS short camera, whereas the VBS functionality has required the addition of both a changed gain control of the cameras and the recognition modules for both non-cooperative and the cooperative short range operations.

In order to better understand the operations of the VBS system, let's follow one of the mission scenarios from afar to close up. Assume that the Chaser satellite is approaching the Target satellite from afar. This scenario is depicted in figure 3. Since the VBS requires that the target is viewed by at least one camera, the first job is to locate and start tracking the satellite.



The Far range upper limit is set by the orbit in the PRISMA mission.

Acquisition and Tracking at Far Range.

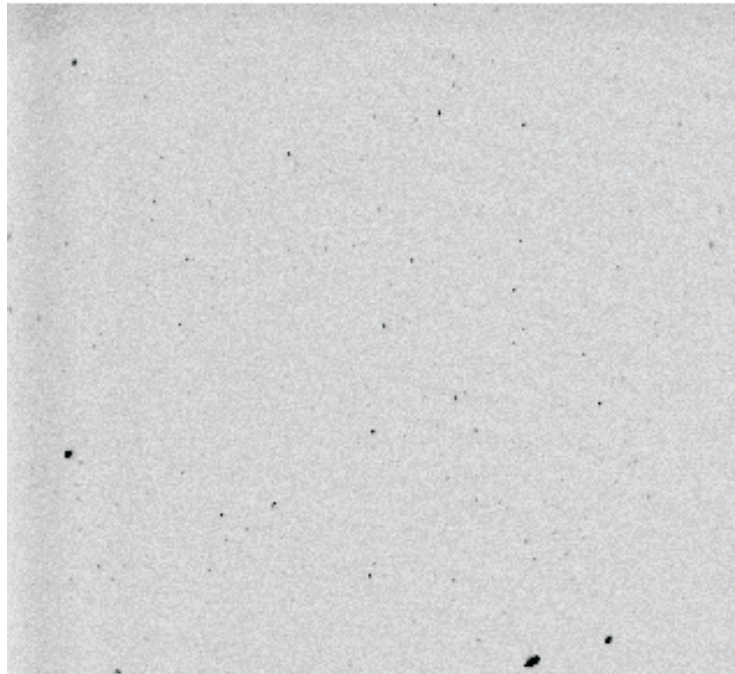
The two VBS cameras are located on the side of the Chaser, which nominally will face in the direction where the Target is assumed to be. At a distance of 1-2000km the target is a faint dot on the

night sky. The acquisition is initialized by the VBS system switching into Far mode that commands the Far camera into nominal star tracking mode. In this mode, the camera image is processed to deliver a normal star based attitude. This processing takes the image through the following steps; the image is being sifted

for all stars detectable, the measured stars are being compared to the onboard star catalogue, based on which the attitude of the camera is calculated. This process automatically marks any luminous object, not found in the star catalogue as a non-stellar object. Typically any image of a star tracker in orbit will deliver some 2-20 such objects per image. Our target is one of these objects, but which? If no a priori knowledge of its whereabouts exists, the answer to this question will only be available after the processing of the next image. At this time, two lists of non-stellar objects exist. Each list holds the measured position of the non-stellar objects as seen on the firmament, i.e. their apparent right ascension and declination, however, since the Target has moved in its orbit between the two updates, a simple comparison of the lists will reveal which object moved at the correct celestial speed. This approach has proven extremely robust, both towards other satellites moving at approximately the same orbit, and towards glinting when the distant Target satellite is rotating and sending time varying reflexes towards the Chaser. This mode has already been tested in flight by several satellites using the microASC system. The image shown in figure 4, was obtained by the CNES satellite Demeter, and shows a bright non-stellar object. As soon as the VBS has a reliable detection of the distant target, the instant direction to the target is continuously fed to the AOCS system, enabling a robust and extremely accurate navigation during the approach phase. The typical direction accuracy is 3arcseconds that corresponds to a 30m diameter uncertainty circle at 1000km!

Intermediate Range Mode.

As the Chaser approaches, the Target will become ever more luminous, as the solid angle it subtends increases. The increased amount of light will at first improve the accuracy further, but eventually, the luminosity will be so



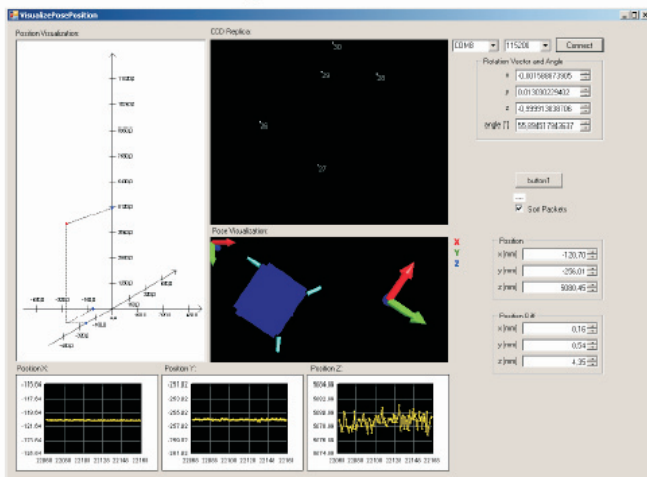
In space, the cameras determine autonomously the coordinates of the unexpected non-stellar object to be located at RA 23h 35' 52" and Dec 33° 08' 59". The object at the bottom right moves with a relative velocity of 2750"/s.

high, that the Far camera will have to activate its shutter to avoid getting bloomed images. At this time, the stars will no longer be detectable, wherefore the system autonomously switches into intermediate range mode. In intermediate range mode, the VBS continues to deliver the pointing direction towards the Target, but now the solutions is delivered in the position measured on the cameras CCD, i.e. relative to the camera system, rather than the global reference frame used in the Far range mode. As the Target approach commences, the VBS short will also start deliver the direction towards the target, i.e. operate in intermediate mode. To give an assessment of the Target distance, the absolute measured luminosity of the target is also provided. The intermediate mode is maintained until the point where the image of the Target on the VBS camera CCDs is large enough to enable recognition of its pose as well, which typically will occur at a distance of 70-120m. The processing that then will take place depends on the commanded state of the target.

Short Range Cooperative Mode.

The Target is equipped with a distinct pattern of fiducial points on each side, in the form of light emitting diodes. In cooperative mode, the diodes are set to deliver one short pulse per second. The VBS Short camera, will in cooperative mode lock on to the light from these points, and by comparing the measured diode pattern to the onboard database, a robust and highly accurate measurement of the Target pose and position is obtained. The processing takes 10-20ms to process, so this information is almost instantly available to the AOCS system of the Chaser. The position of the Target, is as seen by the VBS Short camera, but since it is based on the onboard model, its reference is the actual center of mass of the Target, so formation flying, down to a few cm is achievable using this system. The accuracy of the position is extremely high, typically 100micrometer laterally and 0.5mm distance uncertainty, at a 5m distance between the Chaser and the Target. The pose information is

VBS cooperative mode



Operator panel



Operator room in front of clean room

Testing the VBS cooperative mode in the clean room at SSC. The Chaser with the two VBS cameras are seen at the top right. The Target in a tilted position at the bottom image. And the measured pose and position at the operator panel top left.

typically better than 1deg in all axes at the same distance. In this mode, the VBS continuously delivers the full pose and position solution to the Chaser AOCS. Because this mode is robust towards all illumination cases, safe of direct sun-blinding, it enables very complex docking and circum-flight maneuvers. The operator view of the information delivered in this mode is shown in figure 5.

Short Range Non-Cooperative Mode

When the Target is commanded into non-cooperative mode, the VBS Short and Far cameras will still attempt to recover the Target relative pose and position. However, now the processor is trying to match the acquired image of the target to a 3D model of the Target spacecraft stored onboard.

This matching is based on feature tracking on the target, and is therefore less accurate and more dependent on a reasonable illumination case of the Target. Because PRISMA is launched into a dawn-dusk orbit, the one side of the Target will be in full sunlight and bright, and the opposite side, facing deep space and dark Earth will be entirely dark. Only the side panels is typically receiving a reasonable amount of light, enabling robust recognition. The position accuracy is some ten times worse than what is achieved in cooperative mode, and the pose information some 5 times worse, but the worst constraint of this mode is its sensitivity to the target illumination, which will preclude a full circum flight, because this scenario includes states where no light at all is reflected from the Target to the VBS system.

The Scope

The VBS has proven to be a highly versatile, extremely accurate, robust, and above all fully autonomous navigation sensor system. Because of its very large range, it is capable of covering most of the navigation information needs for fast constellation acquisition and accurate pose and positioning keeping of future formation flying satellites.